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Volume II

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COST EFFECTIVE REPAIR TECHNIQUES FOR TURBINE AIRFOILS

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APRIL 1979

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(U) A program was conducted to establish cost effective repair procedures for conventionally cast turbine airfoils. Components selected for repair were the TF39 first and second stage turbine vanes and the TF39 first stage turbine blade as determined by a Phase I survey of ALC centers. Processes investigated include Activated Diffusion Healing (ADH) of turbine vanes and Activated Diffusion Bonding (ADB) of turbine blades by the mini-bond process. Pilot line processing of Stage I HPT blades provided an unsatisfactory yield due to a need for process control improvements. Action was taken to revise the Stage I HPT blade program to include use of MTL's new and improved mini-bonder and to try furnace ADB for additional attempts at bonding squealer tips and end caps to blade airfoils to obtain higher yields. TF39 Stage I HPT vanes and TF39 Stage II HPT vanes were successfully processed through ADH repair by the Manufacturing Technology Laboratory and shipped to the General Electric Aviation Service Shop in Cincinnati for final processing and inspection. Representative components of each stage were subjected to 1000 'C' cycles in a TF39 engine test vehicle, inspected, and then evaluated to determine the degree of success for each repair.

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This final report was submitted by General Electric Company, Aircraft Engine Group, Cincinnati, Ohio under Contract F33615-76-C-5094, Manufacturing Methods Project 889-6, "Cost Effective Repair Techniques for Turbine Airfoils." Mr. Fred R. Miller, AFML/LTM was the Project Monitor.

This technical report has been reviewed and is approved for publication.


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Project Manager

FOR THE DIRECTOR


H. A. JOHNSON
Chief, Metals Branch
Manufacturing Technology Division

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Pilot line processing of Stage I HPT blades provided an unsatisfactory yield due to a need for process control improvements. Action was taken to revise the Stage I HPT blade program to include use of MTL's new and improved mini-bonder and to try furnace ADB for additional attempts at bonding squealer tips and end caps to blade airfoils to obtain higher yields.

TF39 Stage I HPT vanes and TF39 Stage II HPT vanes were successfully processed through ADH repair by the Manufacturing Technology Laboratory and shipped to the General Electric Aviation Service Shop in Cincinnati for final processing and inspection.

Representative components of each stage were subjected to 1000 "C" cycles in a TF39 engine test vehicle, inspected, and then evaluated to determine the degree of success for each repair. Repair feasibility for both components was satisfactorily demonstrated. However, whereas the Stage 2 repair was found completely successful, the Stage I component evaluation indicated that a modification in ADH alloy would be necessary to restore design integrity to the repaired component.

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FOREWORD

This is Volume II of the final Technical Report for Contract F33615-76-C-5094, United States Air Force, Air Force Systems Command and serves to document the results of the TF39 engine test used to evaluate components repaired under this program.

Volume I included the process development and testing associated with each component repair.

This contract with the Aircraft Engine Group, General Electric Company, Cincinnati, Ohio, was initiated under Manufacturing Methods Project No. IR889-6, "Cost Effective Repair Techniques for Turbine Airfoils." This work was administered under the technical direction of Mr. Frederick R. Miller of the Air Force Materials Laboratory (AFML/LTM), Manufacturing Technology Division, Wright Patterson Air Force Base, Ohio.

The program was directed by Mr. W. R. Young, Manufacturing Technology Laboratory Special Processes Support Project. The principal investigators were Mr. E. L. Kelly and Mr. J. A. Wein of the Repair and Metallurgical Process Technology Unit.

Process Development for the selected repairs was accomplished by the personnel from the Materials and Process Technology Laboratories under the direction of T. F. Berry. Messrs. D. L. Keller, M. K. Mizell, and D. L. Resor performed tests and developed procedures for fluoride ion cleaning and healing of cracks. Mr. J. W. Zelahy assisted in development of mini-bonding process and procedures. Messrs. H. E. Lynch, J. H. Cohen, and J. I. Miller of Repair Development Engineering assisted in defining design criteria and subsequent conduct of the engine test and evaluation.

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SECTION I

INTRODUCTION

Advanced turbine blades and vanes require the use of sophisticated air cooling techniques, costly nickel and cobalt base alloys, and extensive surface protective coatings. Because their operating environments cause various types of degeneration which ultimately lead to their removal and replacement, cost effectiveness of repair versus replacement must be considered in terms of overall life cycle management.

The purpose of the program initiated by Contract F33615-76-C-5094 was to establish cost effective repair techniques for conventionally cast turbine airfoils. The overall program objectives were:

- Select repair processes and airfoil types with generic application to ALC repair requirements.
- Transition advanced process to manufacturing technology.
- Verify repair procedures by pilot line production and component and/or engine test qualifications.
- Involve the Air Logistics Centers (ALC) at program inception with participation throughout to enable timely transition to the ALC's.
- Assess repair costs throughout the program to assure cost effectiveness when related to new part replacement cost.

To accomplish these objectives, General Electric conducted a four-phase manufacturing technology program within the Aircraft Engine Group. A team of contributors was assigned from Group Engineering and Group Manufacturing Divisions. By combining the disciplines of repair design, process development, manufacturing technology, and the Aviation Service Shops, the program was designed to insure rapid transition of repair technology to advanced turbine airfoils.

During Phase I, Repair Selection, a survey of ALC's was conducted. It resulted in the selection of TF39 high pressure turbine first and second stage vanes and first stage blades as the generic repair components.

In Phase II, advanced processes were transitioned to manufacturing to establish the repair procedure. Each repair component was processed through a forty piece pilot line to insure manufacturing process control and repeatability. The pilot line concept was used to provide an accurate assessment of the repair cost. Repair integrity was verified both by non-destructive inspection of appropriate coupon specimens and also by component metallographic examination.

Phase III included engine testing of components to qualify the repair procedure and Phase IV required documentation of the repair procedures by review and issuance of technical orders for repair of each component and analysis of the cost effectiveness of each repair.

Due to an unsatisfactory process yield obtained during the mini-bond repair of stage 1 HPT blades, it was decided to rerun the scale-up pilot line using improved materials and processes. These results along with the results of the engine test hardware are included in this second volume of the final report.

SECTION II

EVALUATION OF PILOT LINE REPAIRED HARDWARE

Forty pieces (plus several extras) of each component, Stage 1 and 2 high pressure turbine vanes, were processed through the pilot line operation described in Volume I of this final report. A 100% yield was obtained for each component as indicated in the previous report.

Twelve of the Stage 1 vanes and fifteen of the Stage 2 components were then submitted for evaluation in a TF39 test engine. The specific test cycle experienced by these components is referred to as a "C" cycle and is shown in Figure 1. This engine and the repaired components were cycled 1000 times through the identified "C" mission profile and then removed for evaluation. Visual examination of the Stage 2 repaired vanes indicated performance equivalent to a new part and significantly better than a weld repaired part. This successful performance, however, was not obtained on the repaired Stage 1 vanes. A majority of the repaired areas were found to exhibit cracking and in virtually all cases the degree of cracking exceeded that observed on new or weld repaired components. Subsequent evaluation revealed the cause which had already been anticipated because of a previous test conducted on CF6 components using the repair process developed in this program. The individual components listed below were those selected for engine test with a further indication for those evaluated by metallographic examination.

COMPONENTS REPAIRED, ENGINE TESTED AND EVALUATED

Component	S/N	Engine Test	Metallurgical Evaluation
Stg 1 HPTV	62759	X	X
↑	63270	X	
	64142	X	
	65565	X	
	68508	X	
	69510	X	
	70171	X	X
	70228	X	X
	74092	X	
	74198	X	
	79482	X	
↓	80106	X	

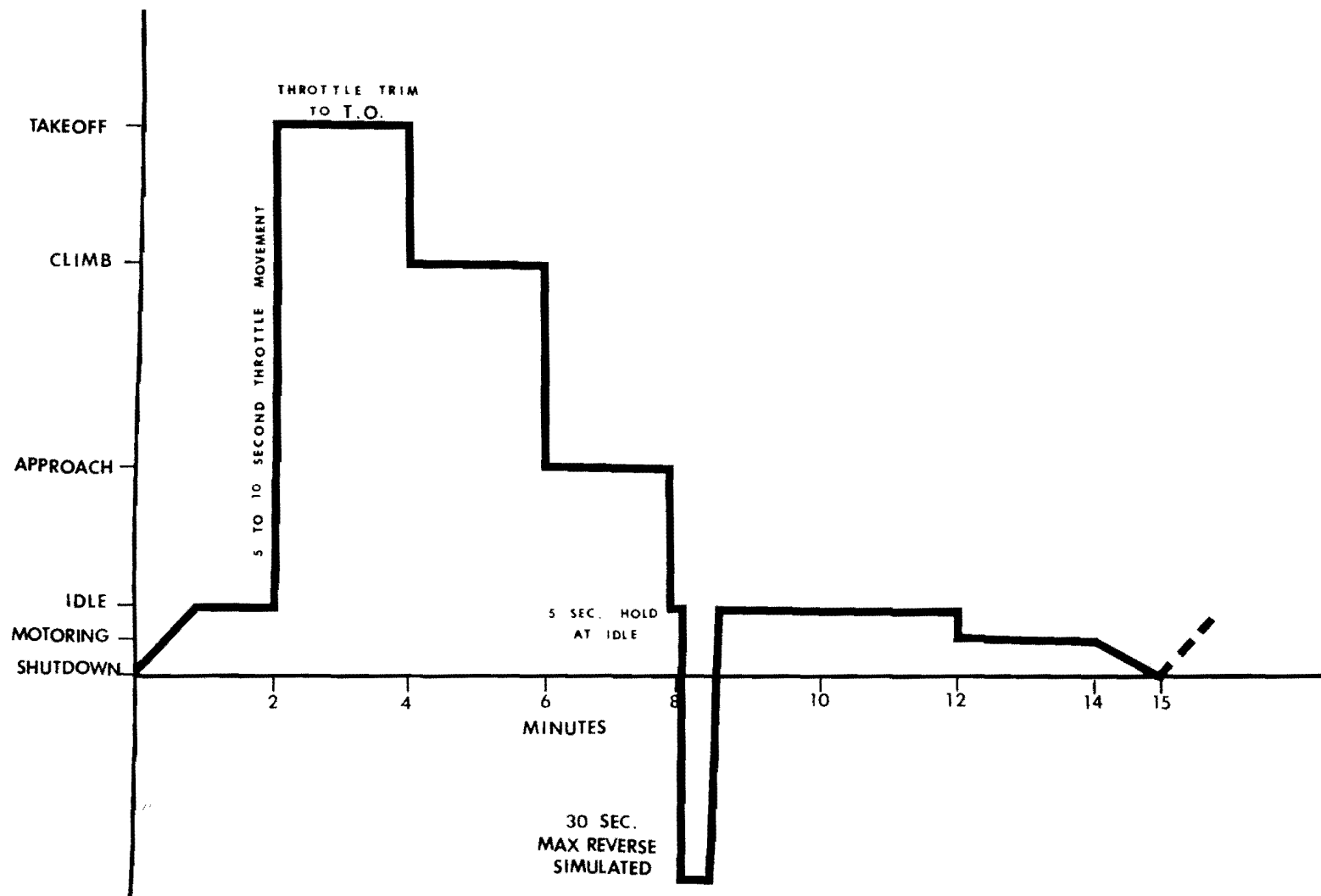


Figure 1. Mission Profile for TF39 "C" Cycle

COMPONENTS REPAIRED, ENGINE TESTED AND EVALUATED (Cont.)

Component	S/N	Engine Test	Metallurgical Evaluation
<div style="display: flex; align-items: center;"> <div style="width: 20px; height: 100px; border-left: 1px solid black; margin-right: 5px;"></div> <div style="writing-mode: vertical-rl; transform: rotate(180deg);">↑</div> </div>	21026	X	
	25550	X	
	31653	X	
	37248	X	
	38034	X	
	45883	X	
	49056	X	
	52026	X	X
	52362	X	
	54936	X	
	54954	X	X
	55917	X	X
	60232	X	
	65491	X	
	76651	X	

Stage 1 High Pressure Turbine Vane Repairs

Repairs performed on the Stage 1 HPT vane incorporated cracked areas of the leading edge, trailing edge (concave surface) aft of the cooling holes and various inner and outer platform locations. Build-up surface repair was accomplished on the tang hole surface and forward and aft seal slot surfaces. No evidence of cracking or excessive wear was noted on any build-up surface repair. Approximately 80% of all locations repaired with the X-40/H-33 ADH alloy were found to exhibit cracking after the 1000 "C" cycle test. Substitution of a X-40/D-15* mixture on CF6-6 Stage 1 HPT vanes processed subsequently and tested earlier indicated equivalent performance to weld repair after 2000 "C" cycles, so it can be said that ADH repair feasibility has been exhibited with a recommendation for change from the X-40/H-33 mixture to X-40/D-15. This change was more fully explained in the first volume.

Three Stage 1 vanes were chosen for metallographic evaluation as indicated previously. Figure 2 shows S/N 70228 as it appeared before ADH repair and then after engine test. (In all macrophotographs, the before repair condition is at the top and the repaired engine run condition at the bottom.) Area A is shown as a repair on the convex surface of the lead vane and both visual and metallographic examination (Figure 3) shows this repair as successful. Area B was typical of the repair performed at the lead edge nose holes with the resultant cracking shown in Figure 4. This figure also shows the cracking which initiated in the ADH repair in Area C at the trail edge of the lead vane. Figure 5 again illustrates cracking which occurred in the ADH repair and Figure 6 shows that crack propagation followed the ADH alloy exclusively. Figure 7 shows successful repairs at the trail edge of the lead vane and above the trail edge cooling holes on the trail vane as well as the unsuccessful repair on both vanes at the leading edge. Nearly all repairs attempted on the aft side of both inner and outer platform areas on all twelve vanes were unsuccessful.

*D15 Alloy - 15.3 Cr - 10.3 Co - 3.4 Ta - 3.5 Al - 2.3B - Bal Ni

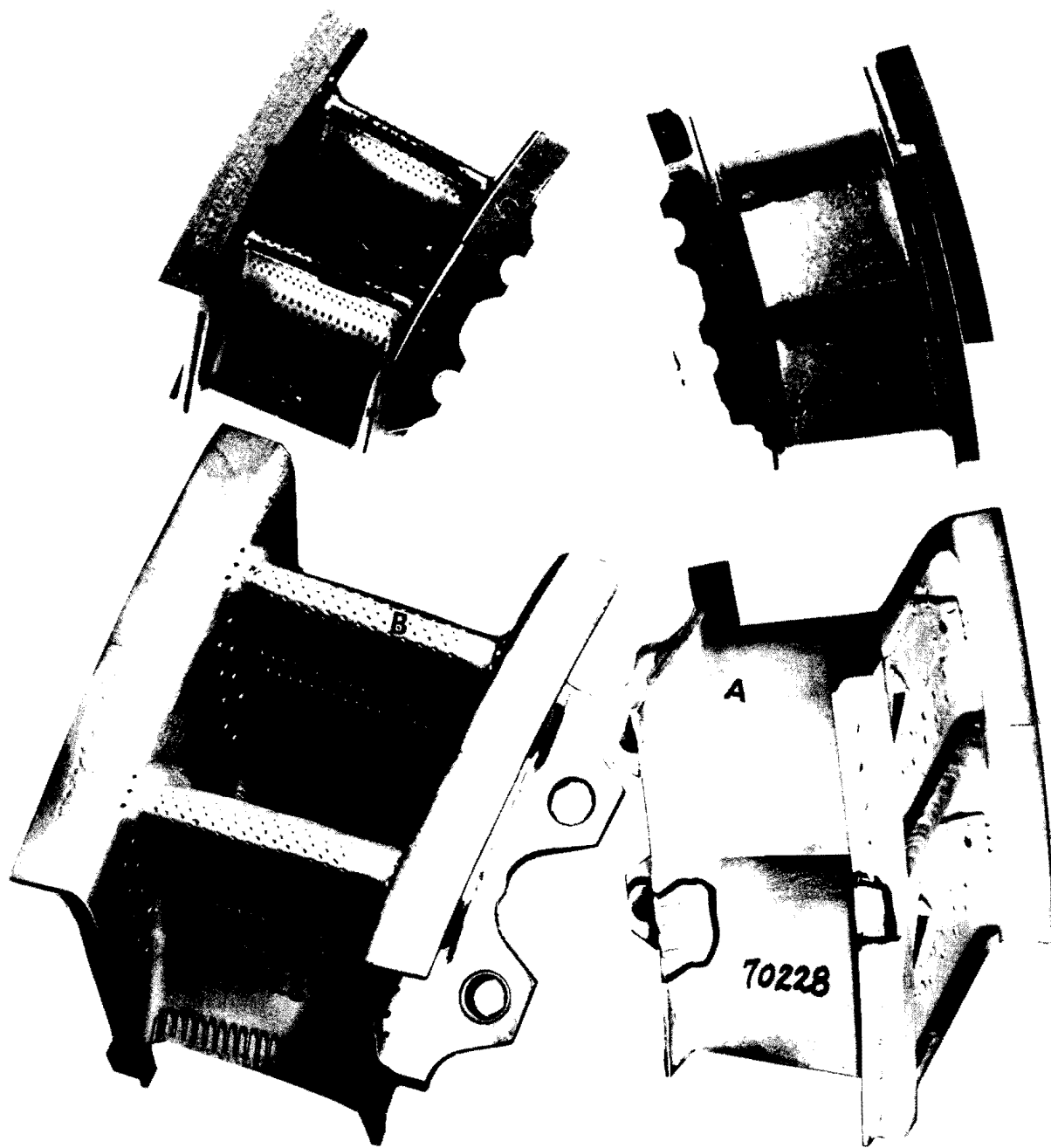
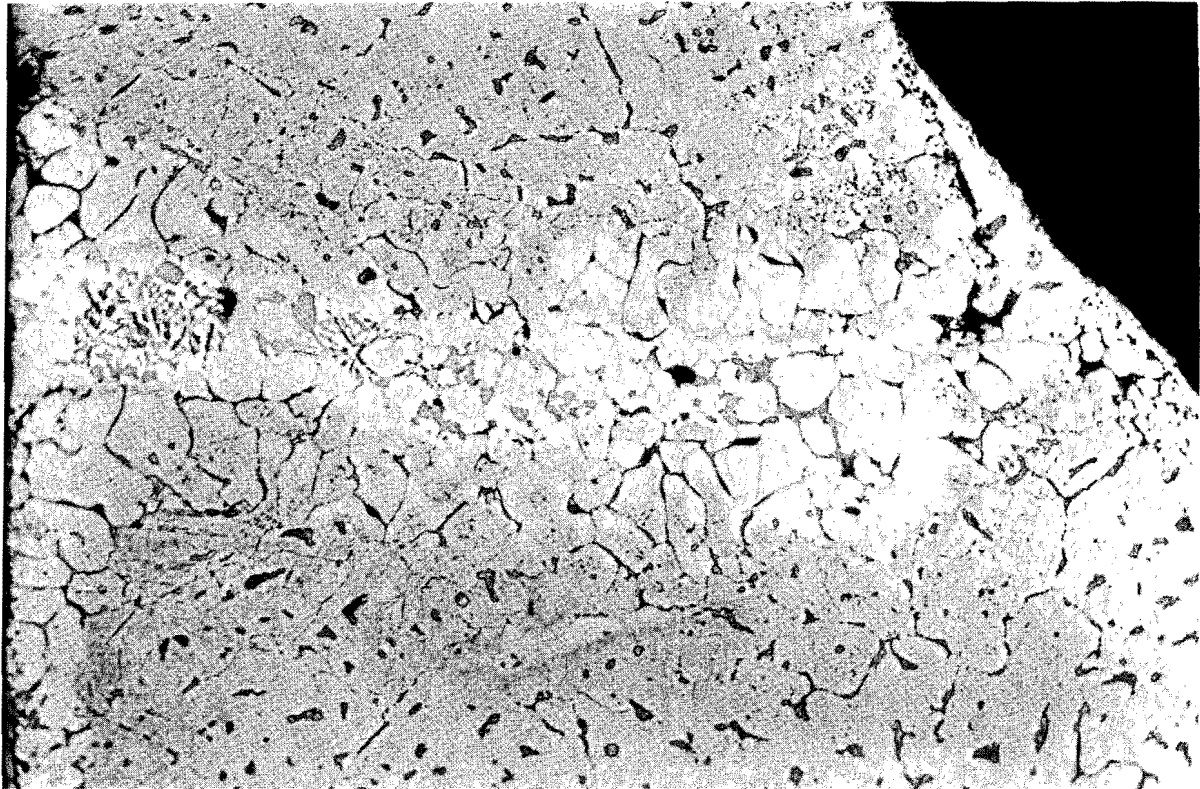


Figure 2. Stage 1 HPTV, S/N 70228, Before ADH Repair and After 1000 Cycle Engine Test



100X

Figure 3. Photomicrograph in Area A on Stage 1 HPTV, S/N 70228
Showing Successful ADH Repair After Engine Test



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Figure 4. Microsection Through ADH Repair on Stage 1 HPTV, S/N 70228, Showing Engine Induced Cracking in Areas B (upper) and C (lower)

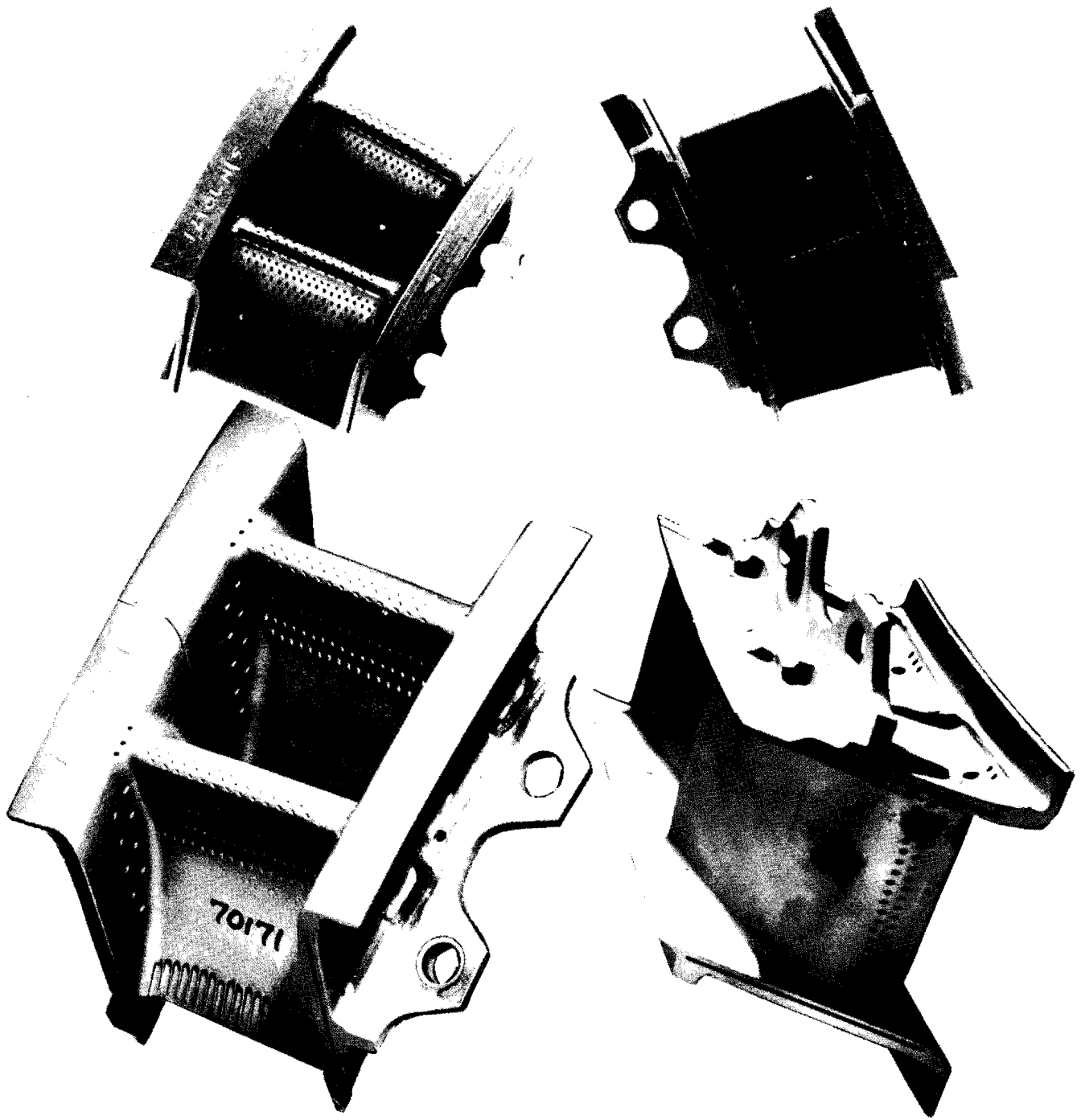
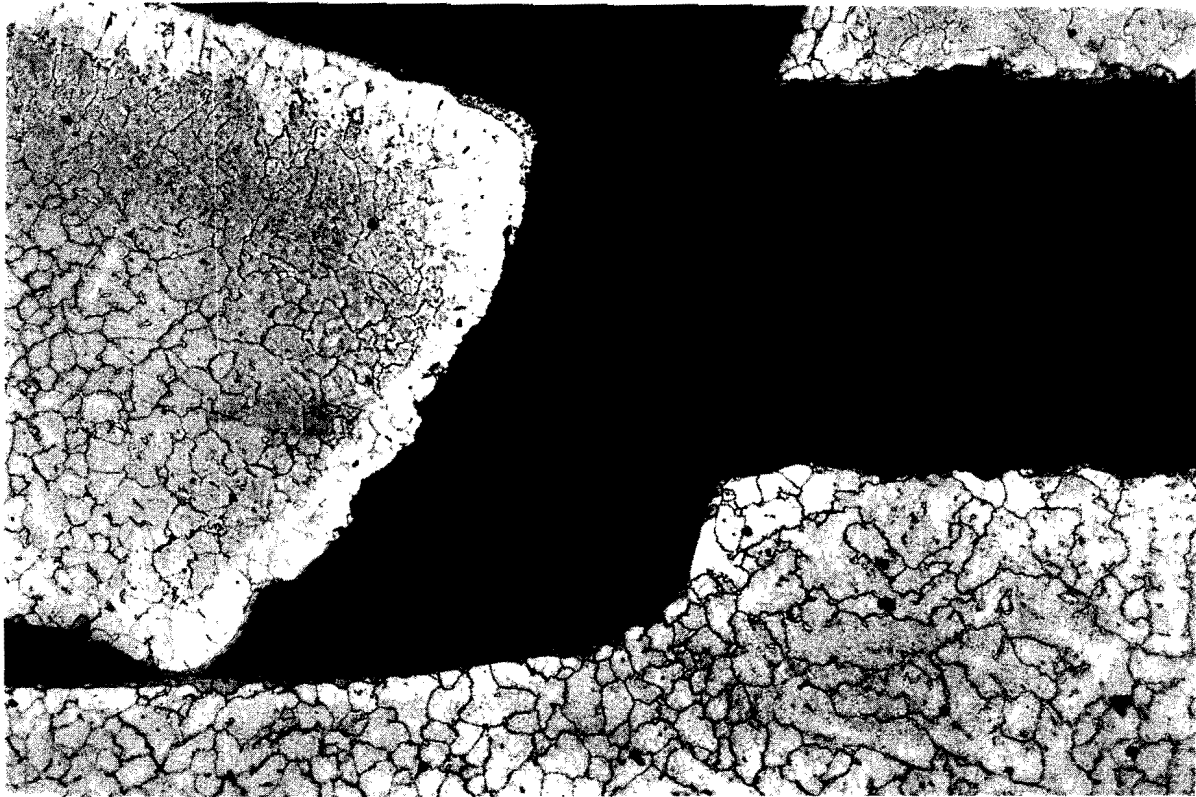


Figure 5. Stage 1 HPTV, S/N 70171, Before ADH Repair and After 1000 Cycle Engine Test Showing Area Examined Metallographically



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Figure 6. Photomicrograph of Section in Area A on Stage 1 HPTV, S/N 70171, Showing Engine Induced Failure Through ADH Alloy and Repair

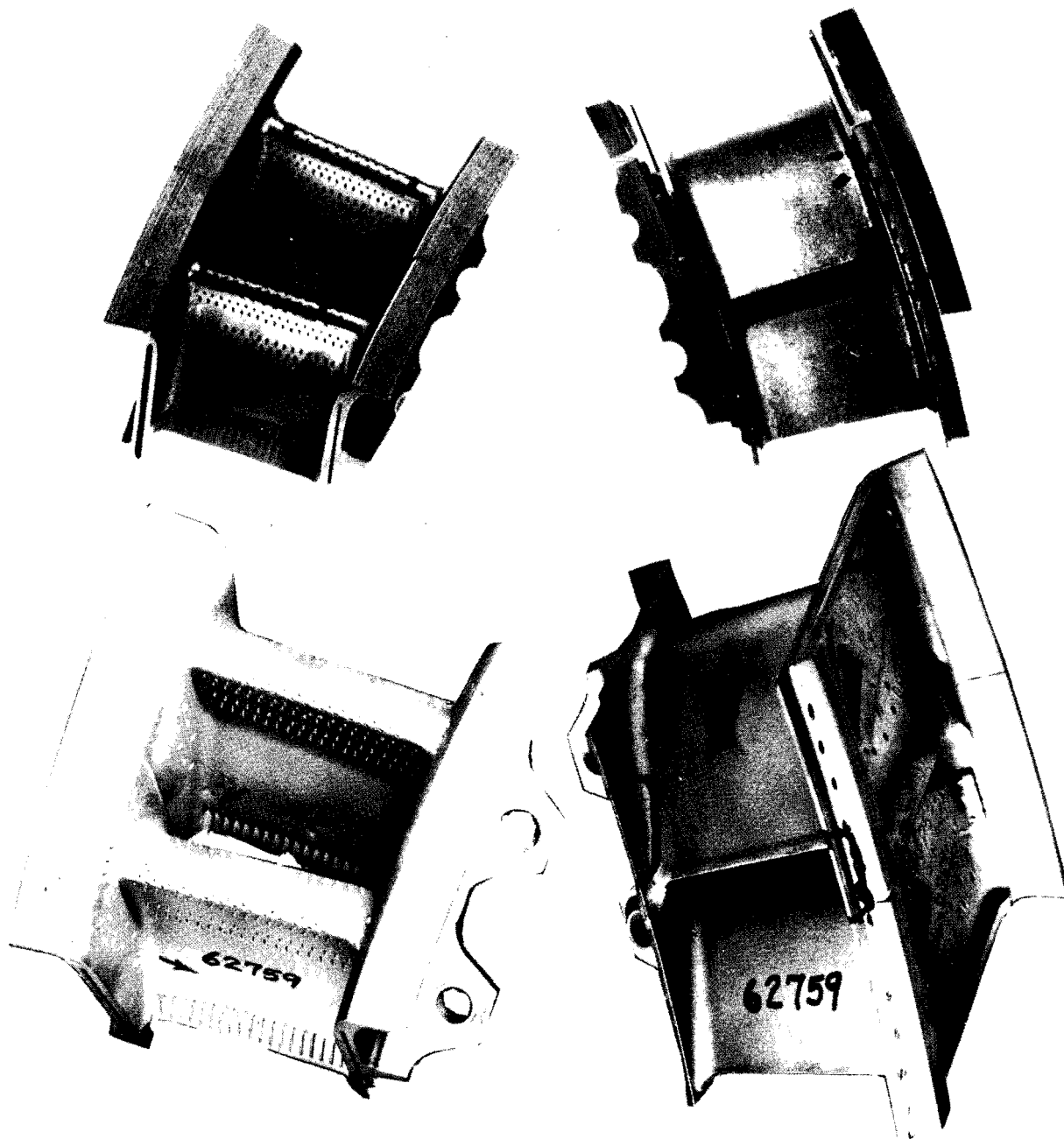


Figure 7. Stage 1 HPTV, S/N 62759, Before ADH Repair and After 1000 Cycle Engine Test Showing Successful ADH Repair

Stage 2 High Pressure Turbine Vane Repairs

The Stage 2 HPT vanes which were selected for repairs had been previously repaired by welding which was not known at the time of selection. Additionally, the amount of distress observed was not too significant; however, in the areas where ADH repairs were accomplished, they were 100% successful after the 1000 cycle engine test. All cracks observed on the test engine run components occurred where a weld repair had been performed. The following photographs and microsections are representative of the observations made on the Fluoride Ion cleaned and ADH repaired Stage 2 HPT vanes. Figure 8 shows S/N 54954 which had an ADH repair performed on the outer platform (Area A) and the trailing edge of the lead vane. Area B is representative of cracks found at the leading edge and/or trailing edge after engine test. Figure 9 shows these respective areas where the ADH repair was successful and where cracking occurred through a weld repair. Figure 10 shows another Stage 2 vane which had repairs performed as indicated by the circled defects and then Areas A and B examined metallographically after engine test. Figure 11 shows the result of this examination with successful ADH repairs of both a parent metal and weld metal crack. Figure 12 shows a Stage 2 HPT vane again typical of successful ADH repair and engine induced weld repair cracking. Of note on this component, however, was an incomplete ADH repair in the outer platform area (Figure 13) which successfully passed the engine test, i.e., no crack indication at visual or fluorescent penetrant inspection. This photomicrograph indicates satisfactory cleaning but lack of enough ADH alloy to flow through the entire crack. These three components serve as typical examples of the remaining vanes which had been subjected to the 1000 cycle TF39 engine test.

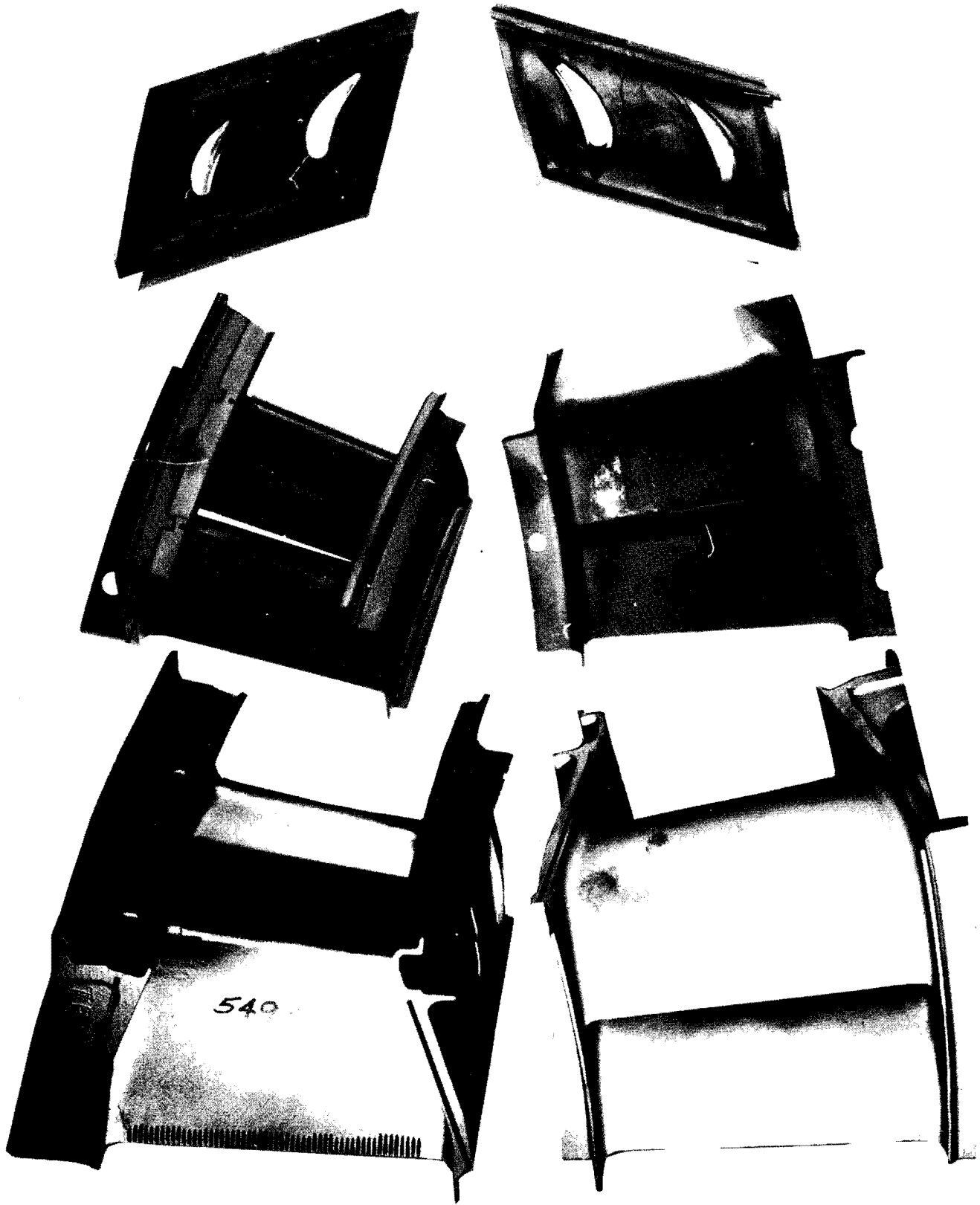
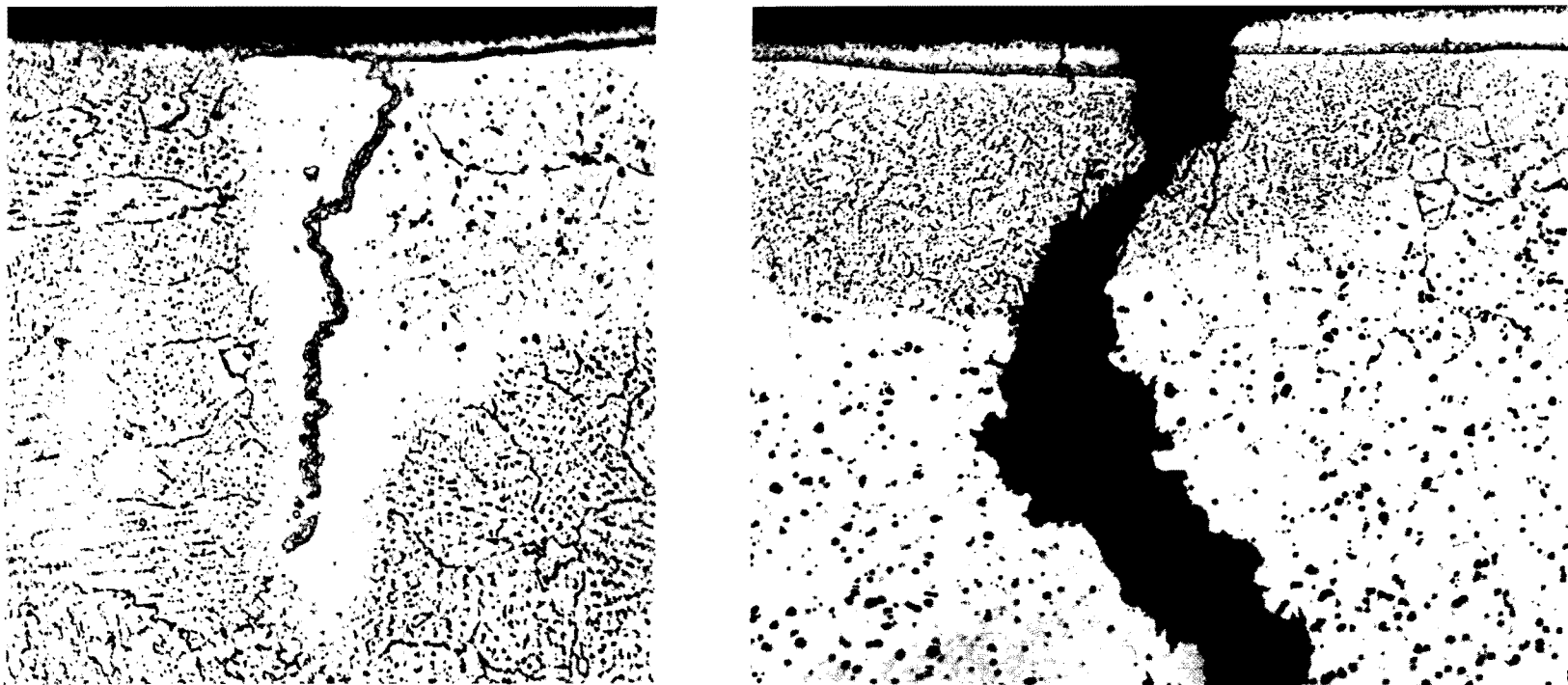


Figure 8. Stage 2 HPTV, S/N 54954, Before ADH Repair and After 1000 Cycle Engine Test Showing Areas Examined Metallographically



100X

LEFT: SUCCESSFUL ADH REPAIR OF PRIOR WELD CRACK IN AREA A
RIGHT: ENGINE INDUCED CRACK OF WELD REPAIR IN AREA B

Figure 9. Microphotographs of Sections From Area A and B of Stage 2 HPTV, S/N 54954
After 1000 Cycles Engine Test

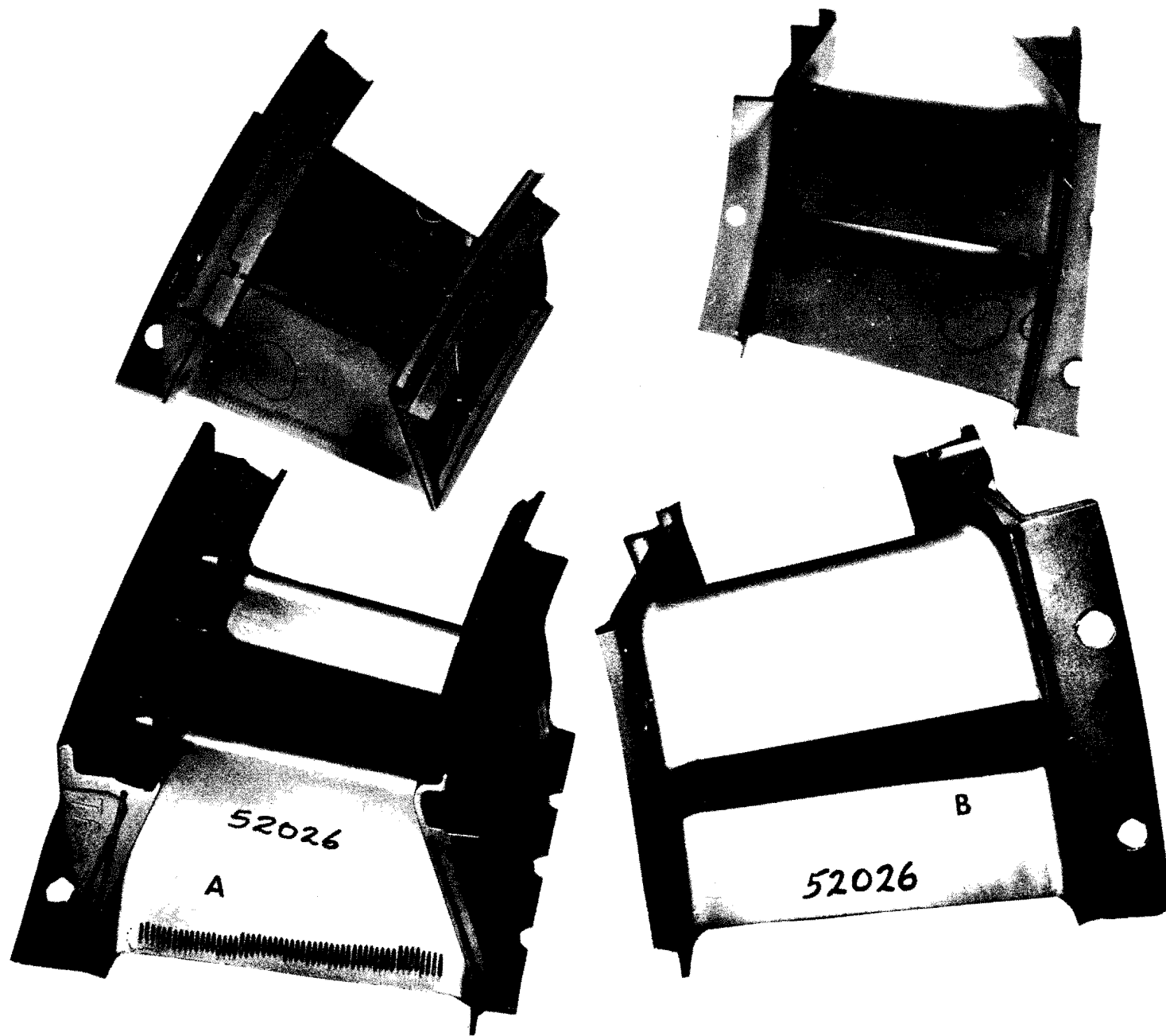


Figure 10. Stage 2 HPTV, S/N 52026, Before ADH Repair and After 1000 Cycle Engine Test. Areas A and B Examined Metallographically.



100X

LEFT: SECTION OF AREA B SHOWING SUCCESSFUL ADH REPAIR OF CRACKED
WELD REPAIR

RIGHT: SECTION OF AREA A SHOWING SUCCESSFUL ADH AIRFOIL REPAIR

Figure 11. ADH Repair on Stage 2 HPTV, S/N 52026, After 1000 Cycle Engine Test

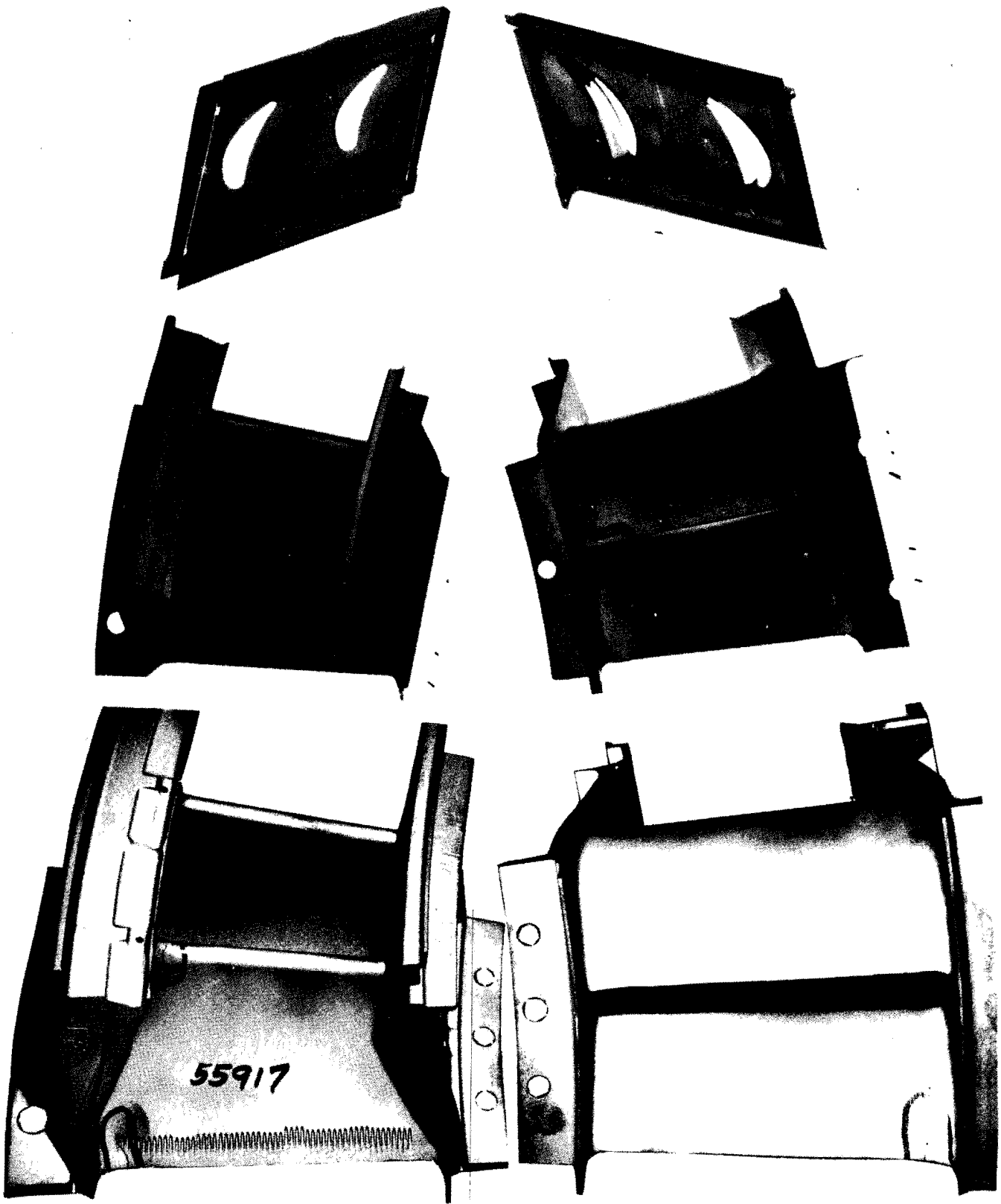
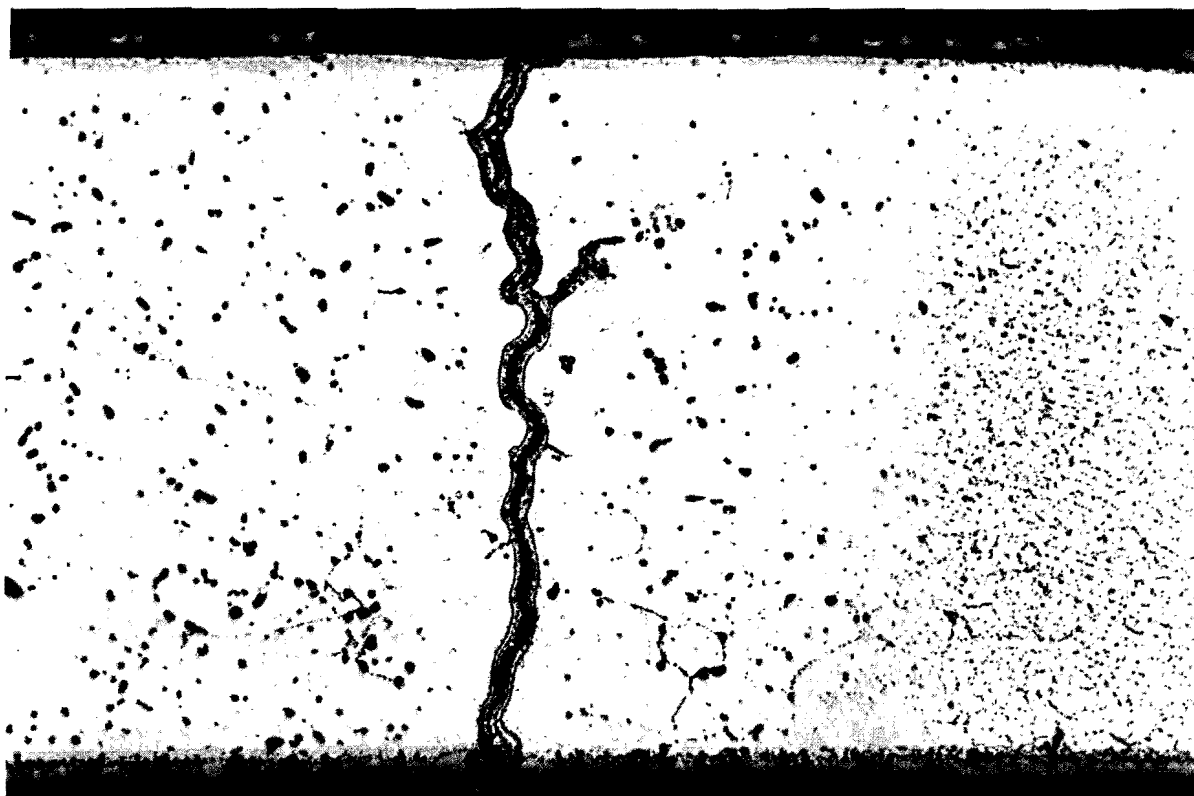


Figure 12. Stage 2 HPTV, S/N 55917, Before ADH Repair and After 1000 Cycle Engine Test



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Figure 13. Incomplete ADH Repair on Outer Platform Stage 2 HPTV, S/N 55917,
After 1000 Cycle Engine Test

SECTION III

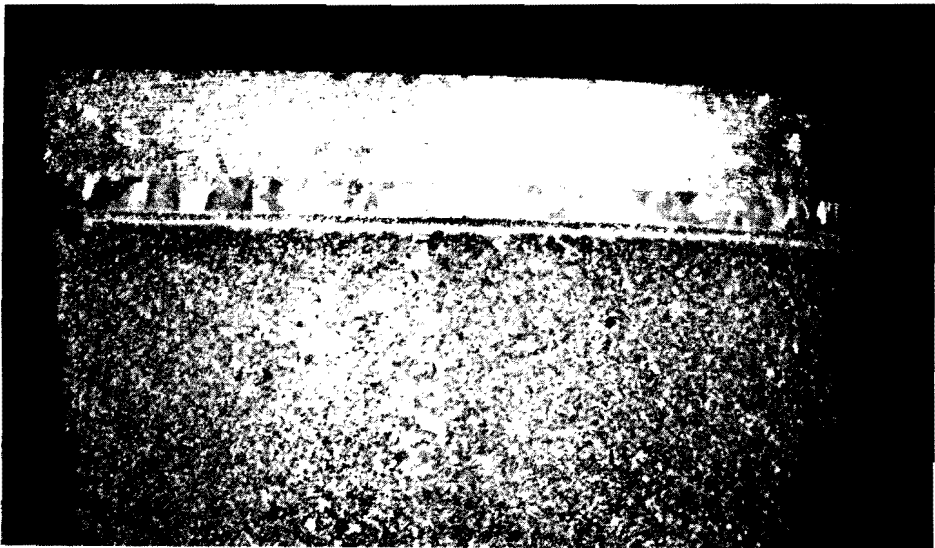
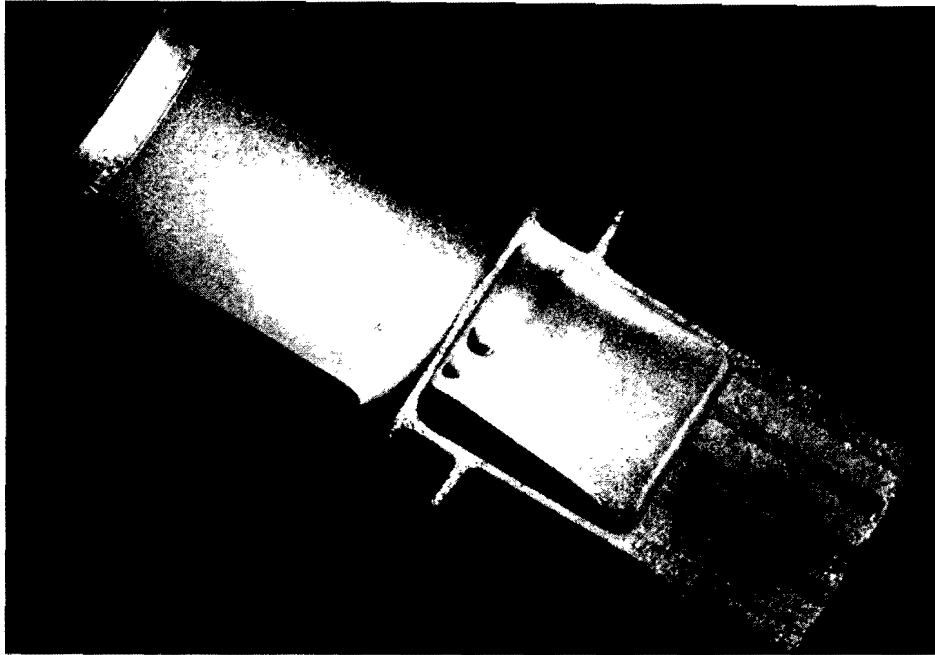
REPAIR PROCESS FOR TURBINE BLADE AIRFOILS

The basic repair process developed for the TF39 Stage 1 HPT blade tip repair consists of the same process identified in Volume I utilizing a furnace ADB cycle to join both squealer and tip cap in place of the mini-bond process which had resulted in low yields due to inadequate process controllability. The furnace ADB cycle resulted in a very successful and controllable joint. Component evaluation was limited to metallographic examination only due to the time restrictions imposed on program completion. Figure 14 shows a repaired blade with a Rene' 80 tip cap and HS188 squealer joined by the ADB process with subsequent dimensional restoration of the tip geometry. Figure 15 is a photomicrograph which shows the structure at the tip cap-airfoil wall joint after the super diffusion cycle was completed. This component followed the sequence previously identified with the following exceptions:

- a. Vacuum furnace ADB at 2200°F/30 minutes and 45 psi applied pressure in place of the mini-bond cycle.
- b. Use of D15 alloy preforms in place of the original presintered D15 alloy.
- c. Utilization of a diffusion cycle to eliminate borides formed during ADB.

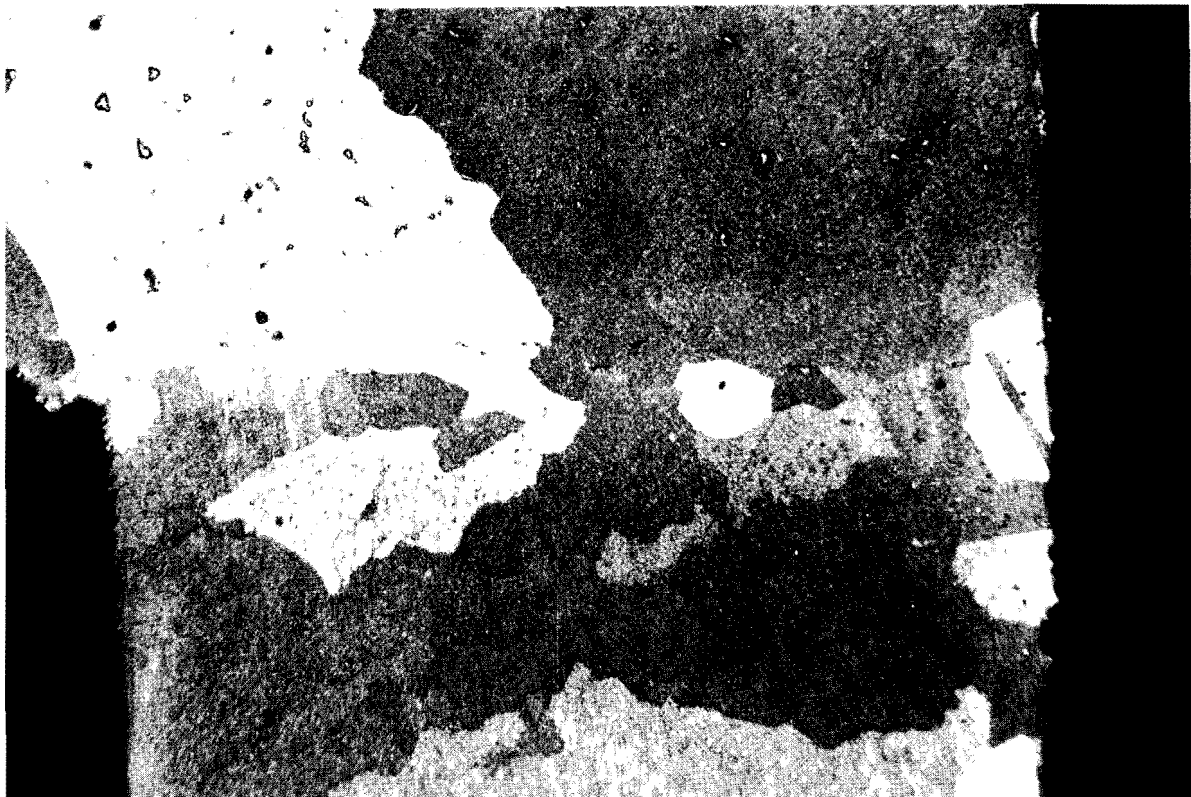
The diffusion cycle included step processing in vacuum at 2000°F, 2100°F, 2175°F for two hours each, then cool to 2000°F for four hours additional and cool to room temperature. Components processed to this procedure are to be tested in both component fatigue and a suitable engine test vehicle as the equipment and resources become available.

The initial results indicate both feasibility and controllability of process and utilization of this process for functional repair of turbine airfoil blade tips appears quite promising.



100X

Figure 14. Stage 1 HPTB Showing Furnace ADB of Rene' 80 Tip Cap and HS 188 Squealer Tip



100X

Figure 15. ADB Joint Between Tip Cap (Upper) and Airfoil Wall (Lower) After Diffusion Heat Treatment

SECTION IV

COST EFFECTIVENESS OF REPAIR PROCESSES

Rationale for Airfoil Repair

There are many potential benefits which may be accrued by repair rather than replacement of engine airfoils. The obvious potential reduction in life cycle costs will be properly emphasized; however, other benefits should be considered.

Non-serviceable parts exposed during overhaul frequently have a large percentage of the anticipated service life remaining. Damaged airfoils may, by repetitive repair, attain two to three times the normal replacement life. Such a utilization to near full design life provides a material conservation in keeping with national goals.

In the normal situation, the rationale for airfoil repair versus replacement may be more sharply focused on pay-off in life cycle management cost reductions to the Air Force. The replacement cost per engine overhaul for a specific part, such as Stage 1 High Pressure Turbine Blade, may be expressed as follows:

Equation 1

$$\frac{\text{Part replacement cost (PRC)}}{\text{Engine Overhaul}} = \frac{\text{Total Number of Parts}}{\text{Engine}} \times \frac{\text{Percent Replaced}}{\text{Overhaul}}$$

x unit part replacement cost

In total, replacement cost per engine overhaul for turbine airfoils may be expressed as the summation of each specific part. This is:

$$\frac{\text{Total Airfoil Replacement Cost}}{\text{Engine Overhaul}} = \sum C_1 + C_2 + C_3 + C_4 \dots$$

where C₁, C₂, etc., represent the part replacement cost of each unique part as defined by equation 1.

For life cycle management, the total turbine airfoil replacement cost may be expressed as follows:

$$\frac{\text{Total Airfoil Replacement Cost}}{\text{(per engine per life)}} = (C_1 + C_2 + C_3 + C_4) \times \left(\frac{\text{Number of Overhauls}}{\text{Engine Life}} \right)$$

The cost reduction potential of repair may be determined by examination of the factors which constitute the part replacement cost, PRC, Equation 1. Thus, if Y is assigned as the number of a unique component part requiring replacement at engine overhaul, then

$$\text{Part Replacement Costs (PRC)} = Y (\% \text{ initial scrap not repairable} \times \text{new part cost} + \% \text{ repaired} \times \text{repaired part cost})$$

This Part Replacement Cost can be further expanded to reflect the yield of the repair process. Thus:

$$\text{PRC} = Y (\% \text{ initial scrap} \times \text{new part cost} + \% \text{ repair yield} \times \text{repair cost} + \% \text{ repair process scrap} \times \text{new part cost} + \% \text{ repair process scrap} \times \text{accumulated repair cost when scrapped}).$$

or rearranged:

Equation 2

$$\text{PRC} = Y (\% \text{ initial scrap} + \% \text{ repair process scrap}) \times \text{new part cost} + (\% \text{ repair yield} \times \text{repair cost}) + \% \text{ repair process scrap} \times \text{accumulated repair cost when scrapped}).$$

This basic equation provides a rationale for replacement or repair of airfoils or other component parts at overhaul. For example, if new part cost is given the value of 1, and assuming some typical values for the other variables:

Repair cost = 60% of new part cost

Repair cost when scrapped during repair process = 30% of new part cost

Percent initial scrap = 33% of total parts

Percent repair process scrap = 13% of total parts

Then, part replacement cost for a single part, Y = 1 is:

$$\begin{aligned} \text{PRC} &= (0.33 + 0.13) 1 + (1.00 - (0.33 + 0.13)) (0.6) + 0.13 (0.3) \\ \text{PRC} &= 0.46 + 0.32 + 0.04 = \$0.82 \end{aligned}$$

This illustrates, that under these assumptions, for each \$1.00 of part cost, \$0.18 may be saved by repair. It is important to note that an increase in the percentage of repairable parts which start the repair cycle and increased repair yield also contribute heavily to reduction of replacement cost.

If, for example, initial input was 90% versus 67% and process yield was improved to 95%, then:

$$\begin{aligned} \text{PRC} &= (0.10 + 0.05) 1 + 0.85 (0.6) + 0.05 (0.3) \\ \text{PRC} &= 0.15 + 0.51 + 0.02 = \$0.68 \end{aligned}$$

The cost saving by repair would be increased to \$0.32 per \$1.00 of replacement part cost.

It is also obvious that repair cost as a percentage of replacement part cost is an important factor. If, for example, it is assumed that repair cost is 50% rather than 60% of replacement part cost in the first example, the

$$\begin{aligned} \text{PRC} &= (0.33 + 0.13) 1 + 0.54 (0.5) + 0.13 (0.25) \\ \text{PRC} &= 0.46 + 0.27 + 0.03 = \$0.76 \end{aligned}$$

The cost savings would be \$0.24 per \$1.00 of replacement part cost.

These examples illustrate the importance of identifying a repair process which allows a larger percentage of parts to be repaired without, at the same time, introducing additional process steps which increase repair cost. These examples also stress the importance of repair yield since money spent to process parts ultimately scrapped must be applied against the cost of repaired parts.

In summary, the examples are given to emphasize that increased repairability and increased repair yields are clearly as important as a decrease in actual repair cost.

Cost comparison of Repair Processes

Phase I studies were used to identify and prioritize the repair processes to be used in this program. Phase II included the pilot line processing of each component to the identified repair process to insure manufacturing process control, repeatability, and provide an accurate assessment of the repair cost.

A detailed breakdown of repairable components utilizing an alternative repair technique was performed based on experience gained in commercial engine repair of CF6-6 engines. Repair experience on the CF6-6 commercial engine is considered applicable to the TF39 since the HPT modules are virtually identical. Extensive flight hours have been logged on CF6-6 components and are useful in serving as a guide to potential distress from long time engine operation.

Tables 1 and 2 show the repair allowances with applicable locations defined by current procedures for weld repair of the respective components.

When we look at this data, we can see one of the reasons for cost effectiveness of the ADH repair process, i.e., reduction of non-repairable hardware. Taking into consideration an additional improved process yield as ADH repairs do not experience the distortion problems and dimensional discrepancies observed in weld repair, we see that the ADH repair concept shows a cost savings over the current method of repair and a very demonstrated cost effectiveness then over new part replacement.

TABLE 1
REPAIR LOCATIONS
CF6-6 - VANES STAGE 1 - HIGH PRESSURE TURBINE
X-40 MATERIAL

	CF6-6	%	Current Repair	
Total Inspected	1847	of Total (100)	Commercial	Air Force
Repairable to Current Limits	1232	(67)	Weld replacement trailing edge	Weld replace one vane of pair
Trailing Edge Replacement	885	(48)		
Crack Repair-Platforms, Airfoil, Flange, etc.	347	(19)	Weld all areas	Weld Platform and Flange only
Scrap to Current Limits	615	(33)	None	None
Leading Edge Distress	602	% (98) of Scrap		
Airfoil Distress	13	(2)		

CF6-6 VANES STAGE 2 HIGH PRESSURE TURBINE
R' 80 MATERIALS

		%	Current Repair	
Total Inspected	1452	100	Commercial	Air Force
Repairable	912	(63) % of total	Weld Repair Cracks	None
Scrap (Total)	540	(37) % of total	None	None
		% of Scrap		
Cracks/Airfoil Fillet Radius	221	(41)		
Cracks/Outer Platform 1.0"	115	(21)		
Cracks/Airfoil 0.600"	31	(6)		
Thin Outer Platform	27	(5)		
Metal Deterioration/Outer Platform	15	(3)		
FOD	22	(4)		
Other	109	(20) % of Scrap (7.5% of Total)		

TABLE 2
REPAIR LOCATIONS
CF6-6 STAGE 1 BLADES - HIGH PRESSURE TURBINE
R' 80 MATERIAL

	CF6-6	%	Current Repair	
Total Inspected	658	100	Commercial	Air Force
<u>Repairable - Tip</u>	312	48%	Weld Build-70 Tips	Weld Build-up Tips
Total Scrap	346	<u>52% of total</u>	None	None
Trailing Edge Cracks	263	(76)		
Erosion	14	(4)		
Nosehole Cracks	32	(9.5)		
Rail/Angel Wing Under Min	---			
Nicks & Dents	15	(4.3)		
Other	13	(4)		
Tip Cap Cracks	---	---		
Plugged Holes	4	(1.1)		
Foreign Materials	5	(1.4)		

Utilizing this data, we can further simplify the breakdown resulting in the following tabulation:

<u>Component</u>	<u>No. Inspected</u>	<u>Repairable</u>	<u>Scrap</u>	<u>Repairable by ADH/ADB</u>
Stg 1 HPTV	1847	67%	33%	95%
Stg 2 HPTV	1452	63%	37%	95%
Stg 1 HPTB	658	48%	52%	48%

The accumulated costs associated with the repair processes demonstrated in this program along with an equivalent cost of the current weld repair method are presented below as a function of the equivalent new part cost to protect a competitive position in the commercial market.

<u>Part Designation</u>	<u>New Part Cost</u>	<u>ADH/ADB Repair Cost</u>	<u>Weld Repair Cost</u>
Stage 1 HPTV	1.0	0.33	0.37
Stage 2 HPTV	1.0	0.32	0.39
Stage 1 HPTB	1.0	0.45	0.37

The ADB repair demonstrated on the high pressure turbine blade established a cost effective method for blade replacement. The higher cost associated with this method as opposed to weld repair is due to the additional tip cap replacement which allows inspection of the internal cooling cavities.

The economics of the process for both turbine stator components as well as the one rotor component demonstrate the cost effectiveness of the repair concept in lieu of new part replacement for total engine life cycle management. Additionally the advanced techniques developed in this program utilizing both ADH and ADB technology further extend the capability and cost savings afforded in turbine airfoil repair.

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